International Journal of Applied and Natural Sciences (IJANS)
ISSN (P): 2319–4014; ISSN (E): 2319–4022
Vol. 10, Issue 2, Jul–Dec 2021; 75–84
© IASET

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

LOW-COST PROPOSAL TO MEASURE AIR QUALITY IN AN URBAN AREA: ACAPULCO CASE STUDY

Alfredo Ricardo Zárate-Valencia [1], Antonio Alfonso Rodríguez-Rosales [2] & Maximino Reyes-Umaña [3]

[1,3]Research Professor, Doctorate in Environmental Sciences, Autonomous University of Guerrero, Mexico

[2] Research Professor, Institute of Applied Sciences and Technology, National Autonomous University of Mexico, Mexico

ABSTRACT

The design and construction of a proposal to measure air quality in the urban area of Acapulco, Guerrero, is presented hereby, based on studies conducted on the existing pollution problems due to the growth of the metropolitan area and the lack of infrastructure to determine the current state of pollution accurately. The equipment consists of a Raspberry Picomputer system, sensors for carbon monoxide (CO), particulate matter (PM10 andPM2.5), ozone (O3) and a weather station. The Python programming language was used to construct a management and control system and then evaluate different environmental parameters. The sensors were calibrated using standard gas and statistical references. For the first phase of tests, our management system was installed at Centro de Investigación Científica y Tecnológica de Guerrero, A.C. (Scientific and Technological Research Center of Guerrero, A.C.) (CICTEG). We obtained preliminary results over a total of six months. Our implementation was cheap, required little operating time, and was easily accessible.

KEYWORDS: *Air Pollution, Calibration, Communication Protocol, Low Cost, Sensor, UART*

Article History

Received: 21 Apr 2021 | Revised: 19 Oct 2021 | Accepted: 23 Oct 2021

INTRODUCTION

In recent decades, in urban cities with high population concentrations, various environmental pollution problems have been manifesting. One of these is the air, mainly due to the demographic explosion, migration, and the increase in internal combustion engines and industry. In our case, it has been challenging to implement environmental control policies, the urban area of Acapulco. In 1993, the local authorities acquired equipment to know the air quality. However, they have not been used recurrently and are under the custody of the SEMARNAT (Ministry of the Environment and Natural Resources) delegation. Thus, the National Institute of Ecology and Climate Change (INECC for its Spanish acronym), has established certain pollutants for Mexico called "criteria" (NIECC, 2015): ozone (O3), carbon monoxide (CO), lead (Pb), sulphur dioxide (SO2), nitrogen dioxide (NO2), particulate matter (coarse PM10 and fine PM2.5). When measuring pollutants, the fundamental difficulty is the high cost of installing and operating monitoring stations that comply with the air quality standard.

We used a proprietary methodology to complement existing monitoring data (EPA, 2014) and new technologies with state-of-the-art sensors, hardware, and open-source telecommunications with easy implementation and operation costs.

MATERIALS AND METHODS

Proposal Design

In recent years, more specific efforts have been made in low-cost air pollutant measurements, such as the one developed by (Hu et al, 2016). Hu proposes a device with sensors installed in cars, buses, and even bicycles and send the data to a server using a cell phone. (Velasco et al, 2016) suggested something similar to take advantage of cyclists' trips from a public bicycle sharing system. They accept that the measurements are less accurate, but they could present a study area's vision.

(Becnel et al, 2019) proposed another system, which uses low-cost contaminant monitoring stations; something similar was developed by (Astudillo et al, 2020).

The Requirements Defined in the Project Were the Following

- Microcomputer or microcontroller no larger than 10 X 10 cm, with low power consumption and low heat generation.
- Communication with commercially available mini weather stations as climate data is indispensable for measuring air quality. In general, communication is via serial port, USB, or Ethernet.
- Communication with state-of-the-art sensors, Universal Asynchronous Receiver / Transmission (UART), for communication via USB.
- Easy-to-programme communication protocols to interact with the sensors and the weather station.
- Wi-Fi communication to access Internet as it is essential to send the readings in real-time.
- Programming in robust and easy-to-use languages like Python or C++.

Figure 1 shows the schematic diagram of the Proposal.

The number of sensors is limited to the equipment's computing power and the need to measure the type of contaminants. For example, if we want to measure O3, CO, and Suspended Particles with sensors that read only one pollutant, four USB ports are required, one for each sensor and station.

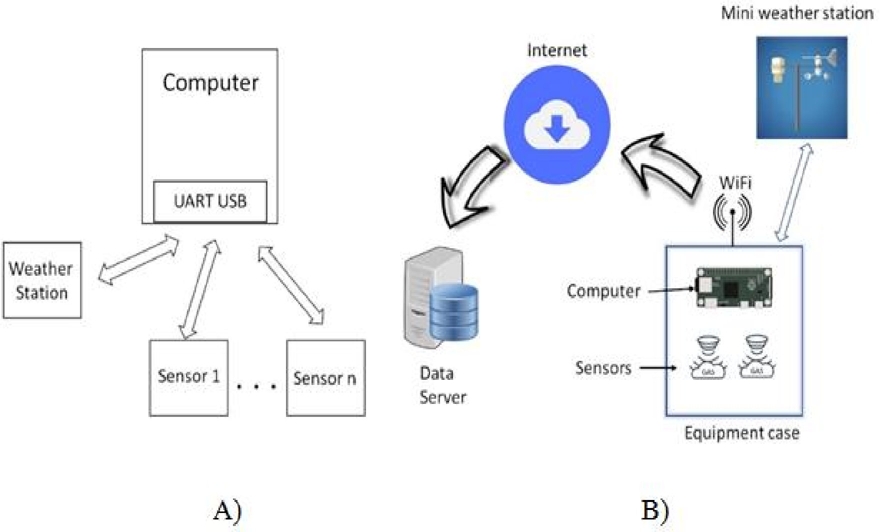


Figure 1: Schematic Diagrams.

Development of Our Proposal

Micro Computer

There are currently two excellent computer boards used as a base for electronics projects: Arduino and Raspberry Pi.

Both are similar in functionality; for example, both have inputs and outputs, microprocessors, memory and can communicate with any sensor on the market. How they perform their tasks is what makes them different.

Although Arduino is used more often in control and sensor projects, it does not have the necessary computing power and ease of use in Wi-Fi access and Internet access, which is needed to send registration data online. We chose to use the Python programming language to develop our communication protocols, as Python can wirelessly connect to the Internet and transmit data; following this choice, the Raspberry Pi 3 B+ was the platform we used.

Weather Station Selection

Meteorological data are incredibly significant when it comes to measuring air quality. Air pollution and climate data correlate with historical climate databases. For example, pollutant dispersion allows determining future behaviour in emissions and climate situations in certain areas (Steiner et al, 2006).

Our selection was Vantage Vue 6250, the only one that has a way to acquire the data directly.

Most Common Sensor Platforms and Their Characteristics

Sensor platforms are a subset of intelligent sensors. They have the functionality to integrate with unspecified external sensors and an interface for programming the microcontroller to perform a specific function (Karvinen et al, 2014).

While the use of low-cost sensors may be promising, challenges include observing the quality of recorded data and technical details such as electronics, calibration, and the correct processing of data (Araújo et al, 2020). Some studies consider that with low-cost gas sensors, it is possible to measure air quality by applying quality control measures (Samad et al, 2020).

Currently, sensor technology is made "Smart." According to IEEE, intelligent sensors have low memory and standardized physical connections to communicate with the processor and the data network (Gervais, 2011). These sensors can process the signal in their code and provide a digital interface, e.g., UART for USB.

Although the sensors are calibrated from the start, their measurement accuracy may be reduced by weather factors or interference from other pollutants (Bauerová et al, 2020). Low-cost sensor systems require frequent (re)calibration, which poses a problem; however, field calibration can help overcome some of these problems (Tancev and Pascale, 2020).

The sensors selected were: DGS-CO-968-034, which measures 0 to 1000 ppm of carbon monoxide; DGS-O3-968-042, which measures 0 to 5 ppm of ozone; and a PM SDS011 laser measurement sensor, which measures 0.0-999.9 µg/m3.See Figure 2.

The first two (DGS-CO 986-034 and DGS-O3 968-042) use electrochemical technology, and the SDS011 uses laser technology. Their full specifications are available on the vendors' website.

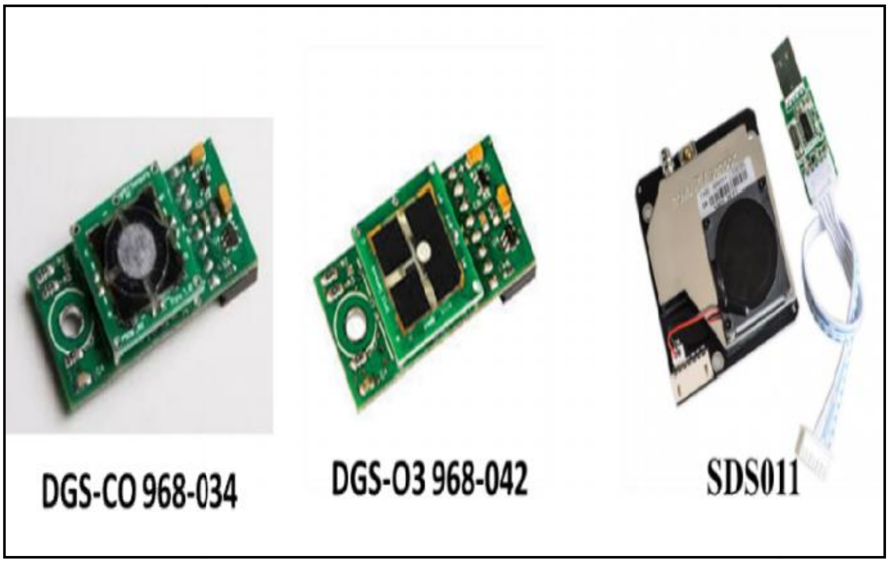


Figure 2: CO, O_3, and Suspended Particle Sensors.

Calibration

Most suppliers provide instructions to follow for calibration at the beginning or after a long period of inactivity. In gas detectors, what is used is the so-called calibration gas (NIECC, 2012), i.e., a gas calibrated by specialized companies to a specific concentration, e.g., 50 ppm. For example, a 50 ppm carbon monoxide standard gas was used for the calibration tests.

We initially calibrated our CO sensor to zero in clean air. In a contaminant-free environment, we let it run until it stabilized, then we let the standard gas in and take readings for several minutes.

Next, we used CO in different concentrations—see Figure 3 for correlations.

Because of its high reactivity, there are no gas standards for the O3 calibration, and these must be calibrated to detect test atmospheres (Godish et al, 2015), which limits our research due to its high cost. The other option is to use other monitors as a reference, which we did with a SEMARNAT monitoring station installed in 2019 in Acapulco.

In order to calibrate the PMs, a reference measurement is required to determine the resuspended standard mass concentration, along with sophisticated laboratory equipment.

SDS011 particle sensor has been used in studies similar to ours— in (Liu et al, 2019); the sensor was used for four months with an accuracy between 80 and 98%.It was Laquai (Laquai and Saur, 2017),who proposed a calibration methodology. In this case, we followed Laquai's proposal, which uses a logarithmic regression as follows:

PM2.5SDS calibrated = PM2.5SDS / (-0.509*ln(PM10 SDS /PM2.5SDS)+1.2203)

Besides, data from official measurements were used as a reference. Another study analysed the performance and calibration of Alphasense gas sensors by a comparison experiment with a national control station 2 km away (Han et al, 2021).

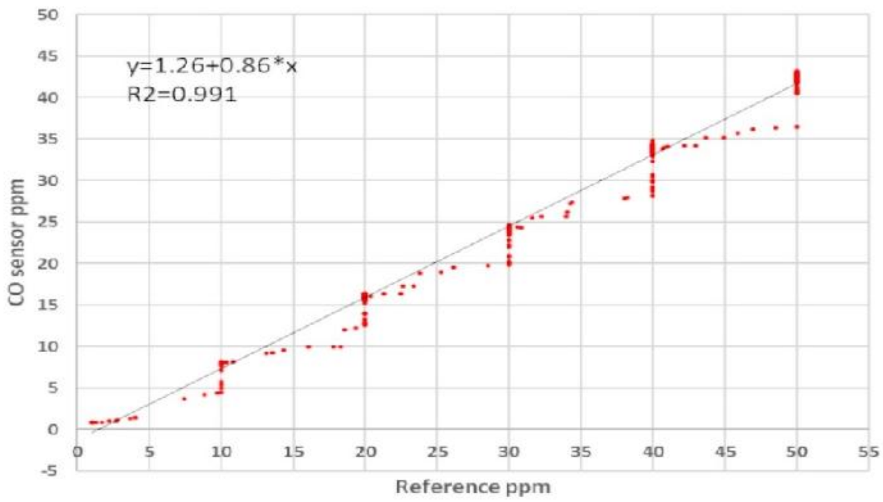


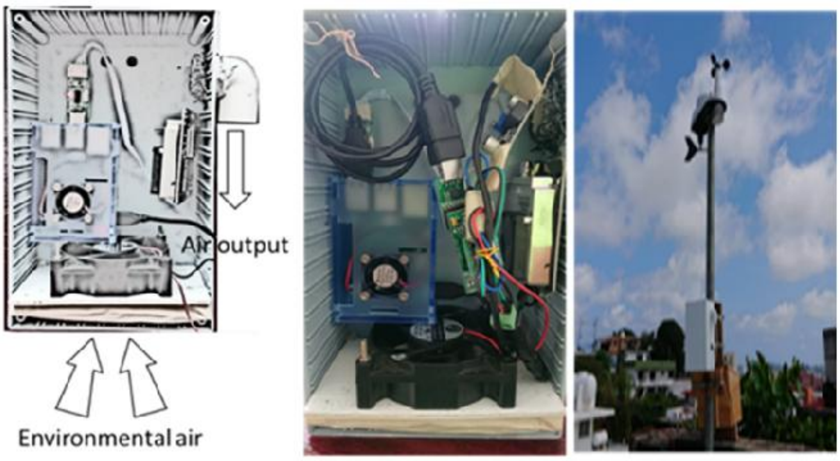
Figure 3: Correlations between Measurements from CO Reference and Sensor.

Proposal Assembly

Based on the methodology and analysis of the different elements required for the design, the guard system was planned. Several sensors were connected to the weather station module and the Raspberry microcontroller, and the electrical system was filtered and cooled, as shown in the diagrams and photographs of Figure 4.

In Figure 4 (A), we see a diagram that outlines how fan air is taken from the environment for two purposes: to sample the gases present in the air to be monitored; to cool the housing interior. Such air is then expelled through the duct on the diagram's right. In some cases, there is a need for a power-free dust disposal device that provides consistent performance without affecting the detection process as dust affects the sensor performance (Kendler and Zuck, 2020). We put a dust filter between the fan and the outside that prevents dust from passing inside the housing.

Figure 4 (B) presents the Proposal assembled inside the housing. The Raspberry Pi can be seen in the background, with sensors connected to its USB ports. Finally, figure 4 (C) contains the assembled Proposal connected to the mini weather station.



(A) (B) (C)

Figure 4: Diagram and Images of the Proposal.

RESULTS AND DISCUSSIONS

As mentioned in the Introduction, our Proposal system serves as a supplement to standardized data monitoring equipment or to verify over a given time and see variations in measurements and record them to establish trends or behaviours.

In our case, an air quality monitoring station was installed in Acapulco in January 2019 by SEMARNAT and located approximately 2 km from our test site.

We compared our measurements with the official monitoring station records, which began operating in January 2019 and unfortunately stopped working mid-September of the same year. In our case, we began testing in February 2019 and recorded data continuously until May 2020; we took the period from “June to august 2019” to perform comparisons.

An essential aspect of our Proposal is that it has integrated meteorological data in conjunction with air quality data interpreted and even make predictions. For example, a 2019 study analysed PM2.5 concentrations in Richmond, Virginia, per hour on the hottest ten days of the year and average daily for the whole year, finding a positive correlation with temperature (Eanes et al, 2020).In the Figure 5 we show some weather data.

Figure 6 shows the wind rose based on the wind direction and speed data recorded in the study period. The predominant direction is to the west with average wind speeds of between 5 and 10 km/h, with peaks of 10 to 15 km/h and lower proportions of 0 to 5 km/h. There are winds of between 5 and 10 km/h in a north-westerly direction to a much lesser extent.

The data recorded in the sensor of our proposal (prototype), for PM2.5A) and PM10 B) are shown in Figure 7. The PM2.5 records maintain a range of 30 to 70 µg/m3, whereas the PM10 records range from 60 to 200 µg/m3 with peaks of 250 µg/m3.

Comparing PM10 and PM2.5 records between our proposal and the official station Figure 8, we retrieved data records in both places. Proposal PM2.5 records maintained in a range of 30 to 70 µg/m3 but concerning official measurements, the range of a recording is between 10 and up to 160 µg/m3.

It is critical to emphasize that we extracted the official station data as a reference for our purposes, though it is not hugely practical for us. The data recorded by the Proposal are very unusual from the conventional ones because, while we average 36.59 (simple arithmetic average) in that period, the official data gives 18.05, ours being more than double. Rarely, the high peaks of up to 163 µg/m3 and in some cases negative values, make us doubt on the records obtained, perhaps they were uncleaned, or something happened with their calibration.

To calibrate the previous data obtained from our Proposal, we used the model proposed by Laquai. Figure 9 shows the data calibrated with the suggested model and the official data. It can be seen there that the data are closer to the official ones but still far from close.

Figure 10 shows a correlation of PM10. The minimum data are around 60 and the maximum data around 200 µg/m3 with peaks up to approximately 250 µg/m3. In the official records, the data are consistently around 1 µg/m3, which is exceptionally rare because, in that period, it is never more than 1.0021 µg/m3.

After comparing the PM10 and PM2.5 particle data from the Proposal and the official data, we wanted to see if the meteorological data of temperature, relative humidity, and wind speed had any relation to the PM2.5and, if so, whether it was significant or not.

Our Proposal cost was approximately USD 1300, with the mini station, sensors, Raspberry Pi, power, and ventilation systems. It is much less than a monitoring station cost to deliver similar data.

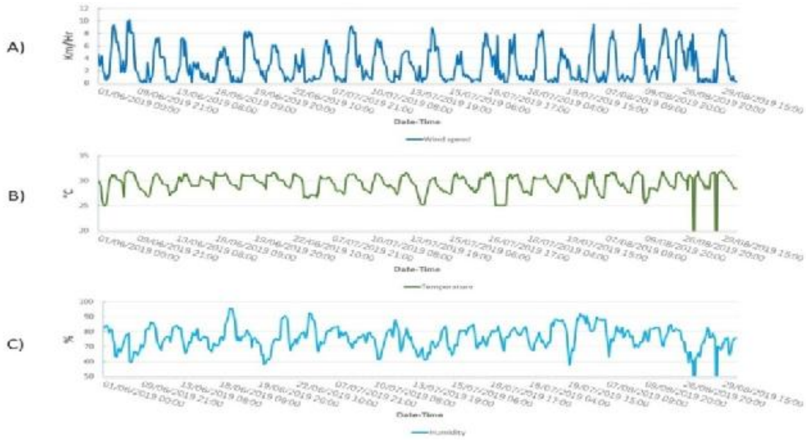


Figure 5: Wind Speed (A), Temperature (B), and Humidity (C) Data.

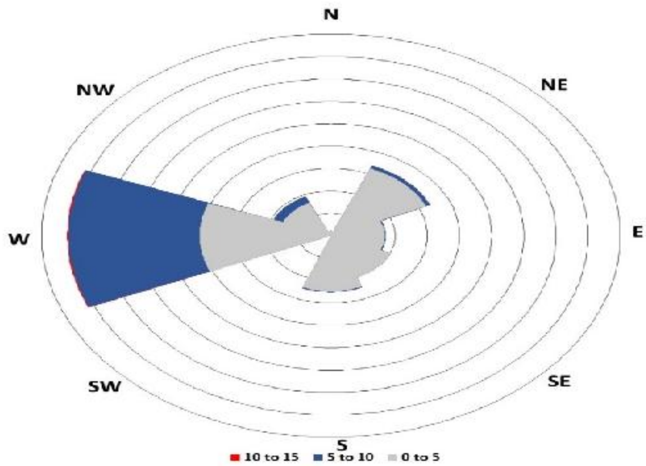


Figure 6: Acapulco Compass Rose.

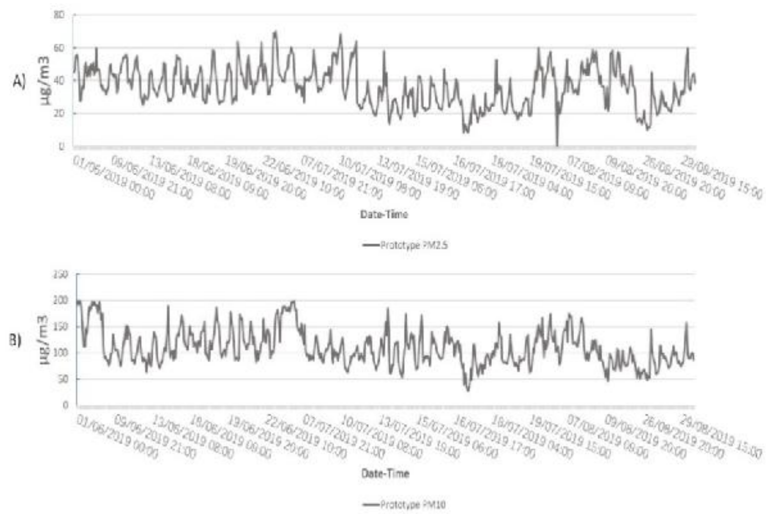


Figure 7: $PM_{2.5}$ and PM_{10} Sensor Data.

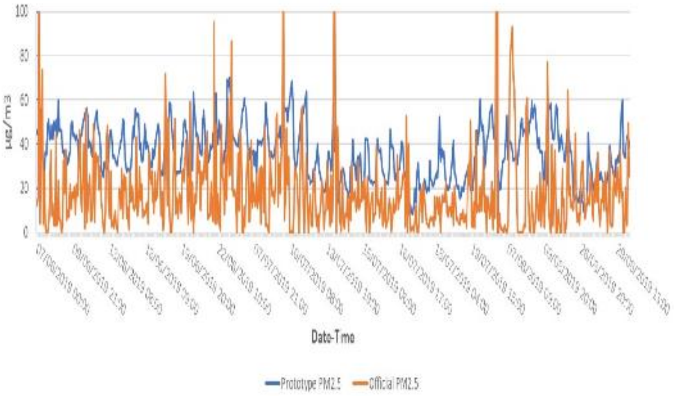


Figure 8: $PM_{2.5}$Proposal and Official Data.

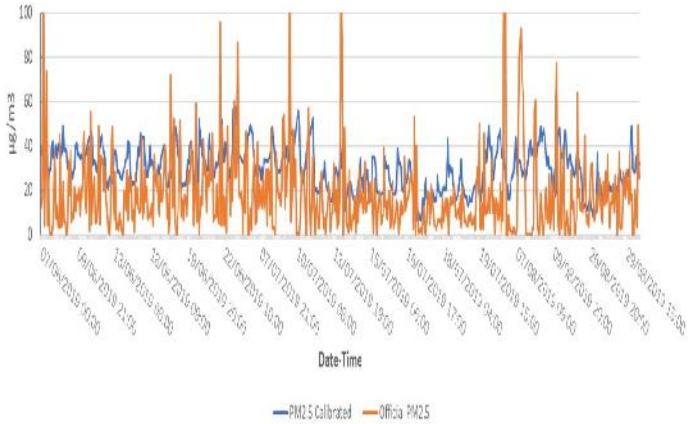


Figure 9: $PM_{2.5}$ Calibrated Prototype and Official Data.

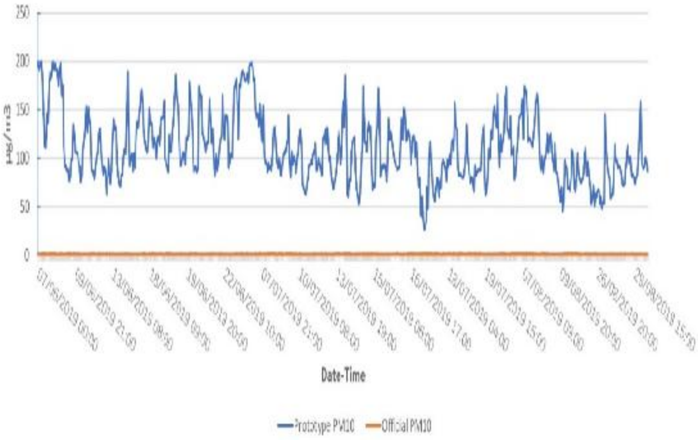


Figure 10: PM_{10} Proposal and Official Data.

CONCLUSIONS

We built an experimental Proposal to complement the existing monitoring data. Air quality was measured in its initial phase using the patented methodology and state-of-the-art technology, whose implementation was cheap, required little operating time, and was easily accessible. Preliminary results indicate a degree of reliability above 70% compared to some commercial systems.

Reliability is undoubtedly lower than with Calibration, Measurement, and Operation equipment backed by EPA or each government. However, if our solution costs 1,500 dollars and gives us readings of about 70 percent, compared to tens of thousands of dollars plus the operating cost of an environmental monitoring station in full compliance, 70 percent becomes higher when it values the cost-benefit.

The point is that our proposal, and indeed that of all of us who use sensors and low-cost equipment, is not to replace official measurements but rather to have tools to look at environmental pollution behaviours and to pay attention to where trends show increases.

REFERENCES

1. *National Institute of Ecology and Climate Change, National Air Quality Report 2014, México, 2015.*
2. *Environmental Protection Agency, Air Sensor Guidebook, USA, 2014.*
3. *Hu K, Sivaraman V, Gallero Luxan B & Rahman A, Design and Evaluation of a Metropolitan Air Pollution Sensing System, IEEE Sensors Journal 2016, 16(5), 1448 1459*
4. *Velasco A, Ferrero R, Gandino F, Montrucchio B & Rebaudengo M, A Mobile and Low-Cost System for Environmental Monitoring: A Case Study., Sensors 2016, 16, 710.*
5. *Becnel T, Tingey K, Whitaker J, Sayahi T, Le K, Goffin P, Butterfield A, Kelly K & Gaillardon PE. A Distributed Low-Cost Pollution Monitoring Platform, IEEE Internet Things J., 2019, 6, 1*
6. *Astudillo-Heras D, Garza-Castañón LE & Minchala-Ávila LI, Design and evaluation of a reliable low-cost atmospheric pollution station in urban environment. IEEE Access, 2020, 8, 51129 – 51144*
7. *Arduino Official Site, ARDUINO UNO REV3, consulted https://store.arduino.cc/usa/arduino-uno-rev3 (accessed on 20/03/2020).*
8. *Raspberry Pi Official Site (2020), Raspberry Pi 3 Model B+, consulted https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus. (accessed on 09/07/2019)*
9. *Steiner AL, Tonse S, Cohen RC, Goldstein AH & Harley RA, Influence of future climate and emissions on regional air quality in California, Journal of Geophysical Research 2006, 111, D18203. Https://Doi.Org/10.1029/2005jd006935.*
10. *Karvinen T, Karvinen K & Valtokari V, Make Sensors: Projects and Experiments to Measure the World with Arduino and Raspberry Pi, Maker Media 2014.*
11. *Araújo T, Silva L and Moreira A, Evaluation of Low-Cost Sensors for Weather and Carbon Dioxide Monitoring in Internet of Things Context., IoT 2020, 1, 286–308.*
12. *Samad A, Obando Nuñez DR, Solis Castillo GC, Laquai B & Vogt U, Effect of Relative Humidity and Air Temperature on the Results Obtained from Low-Cost Gas Sensors for Ambient Air Quality Measurements., sensors 2020, 20, 5175.*
13. *Gervais-Ducouret S, Next Smart Sensors Generation, IEEE Xplore 2011, https://doi.org/10.1109/SAS.2011.5739775.*

14. *Bauerová P, Šindeláˇrová A, Rychlík Š, Novák Z & Keder J, Low-Cost Air Quality Sensors: One-Year Field Comparative Measurement of Different Gas Sensors and Particle Counters with Reference Monitors at Tušimice Observatory., Atmosphere 2020, 11, 492.*

15. *Tancev G & Pascale C, The Relocation Problem of Field Calibrated Low-Cost Sensor Systems in Air Quality Monitoring: A Sampling Bias., Sensors 2020, 20, 6198.*

16. *National Institute of Ecology and Climate Change, Manual 4 Operation of Air Quality Measurement Stations, Maintenance and Calibration of its Components, México, 2012.*

17. *Godish T, Davis WT& Fu JS, Air Quality (Fifth Edition), CRC Press, USA 2015*

18. *Liu HY; Schneider P; Haugen R & Vogt M, Performance Assessment of a Low-Cost PM2.5 Sensor for a near Four-Month Period in Oslo, Norway. Atmosphere 2019, 10, 41.*

19. *Laquai B & Saur A, Development of a Calibration Methodology for the SDS011 Low-Cost PM-Sensor with respect to Professional Reference Instrumentation, 2017.*

20. *Han P, Mei H, Liu D, Zeng N, Tang X, Wang Y & Pan Y, Calibrations of Low-Cost Air Pollution Monitoring Sensors for CO, NO2, O3, and SO2., Sensors 2021, 21, 256.*

21. *Kendler S &Zuck A, The Challenges of Prolonged Gas Sensing in the Modern Urban Environment., Sensors 2020, 20, 5189.*

22. *Eanes AM, Lookingbill TR, Hoffman JS, Saverino C & Fong SS, Assessing Inequitable Urban Heat Islands and Air Pollution Disparities with Low-Cost Sensors in Richmond, Virginia., Sustainability 2020, 12, 10089.*